SHUTTER OF THE ARTESIAN WELL GUSHING ABANDONS IN MONZOUNGOUDO, BENIN

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ABSTRACT

The artesian well of Monzoungoudo has been abandoned since 2005. The non-mastery of artesianism springing up at this water point constitutes a waste of the resource and has caused environmental damage. It is a question of an uncontrolled flow of the artesian well induced by the depressurization of the aquifer, resulting in a potential loss of capacity of neighbouring wells and continuous flow of the well at the mouth of its casing. In contact of the recovered water with the surrounding soil, it may generate local flooding, gullying, soil subsidence, the formation of sinkholes and cause damage to the infrastructures located nearby. In addition, the water from the artesian aquifer on the surface migrates to the Monzoun River, while transporting suspended particles or contaminants encountered on its path. The receiving environment of this water could then be affected by an input of turbid water or various contaminants. All these reasons justify the validity of this study, which proposes to address the technique of plugging the abandoned artesian wells of Monzoungoudo in order to stop or control the gushing water.

Keywords: Abandons; Artesian well; Captive aquifer; Gushing; Monzoungoudo; Shutter.

1 INTRODUCTION

In the locality of Monzoungoudo in Benin, a large proportion of the drinking water consumed comes from water recovered from the permeable underground soils called "aquifers" [1, 2]. To collect water in this locality, a well is usually drilled in the unconsolidated deposits, at varying depths. Depending on the hydrogeological context of this locality, the aquifer exploited by the extraction of groundwater is intercepted at great depth. The wells in this locality show a gushing behaviour [3] (Fig.1), that is to say that the water level in the well exceeds the ground surface.

To fully understand what an artesian gushing well is, one must understand the hydrogeological context in which the well is located [4]. We are talking of an aquifer, or a permeable, porous geological formation, allowing groundwater to flow and withdraw. It is a geological formation made up of unconsolidated granular materials (sand, gravel). The aquifer in question is a captive aquifer. The captive aquifer has a low permeability covering (clay) providing protection against percolation of surface water or against any source of surface contamination of groundwater. The base of this poorly permeable cover corresponds to the roof of the aquifer [5].

Note that the water flowing within a captive aquifer is usually pressurized, i.e., the piezometric surface (the level reached by the water in a well open to the atmosphere) is usually higher than the roof of the aquifer. Since the artesian well of Monzoungoudo cannot be controlled (Fig. 2), this explains the abandonment of the work and its sealing.

The objective sought in the context of this work of filling the artesian well gushing from Monzoungoudo is to recover the hydrogeological conditions of the original aquifer, that is to say, the conditions inherent in the aquifer prior to the drilling of wells, so as to avoid the potential nuisances of the gushing.

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DOI 10.35180/gse-2021-0057

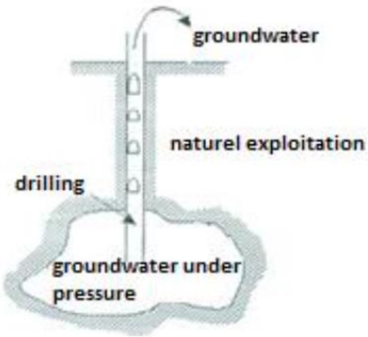

Figure 1. *Artesian well* [3]

Figure 2. *Constant flow of water from the abandoned well in Monzoungoudo* [2]

2 MATERIALS AND METHOD

2.1 Sealing procedure

In the context of this work, the gushing of water is observed around the perimeter of the well, between the casing and the surrounding soil. According to the decision-making process leading to the plugging of a spouting well [6] (Fig. 3) the perimeter of the well should be sealed prior to the plugging work. To do this, several approaches can be considered. These methods consist, in particular, of the excavation or reaming of the outside of the well, followed by the filling of this excavation with a low permeability material (bentonite in granules, cement-bentonite grout, etc.). Depending on the context, it may be justified to avoid sealing work on the outside of the casing and to directly inject dense grout (sealing agent) inside the well. For example, if the composition of the surrounding soils is in part very loose, if it essentially shows the presence of large-diameter aggregates or if the flow gushing outside the casing is important, the recommended sealing works may worsen the situation.

Prior to injection work, the hydrostatic pressure to be alleviated must be assessed. To do this, the height of the water column between the aquifer roof (L) and the piezometric level (H) must be known (Fig. 4). The total length of this water column will provide the hydrostatic pressure to combat when selecting the grout. This total length can be achieved in a number of ways, but the most common methods require the installation of back-up casing or the installation of a pressure gauge at the wellhead.

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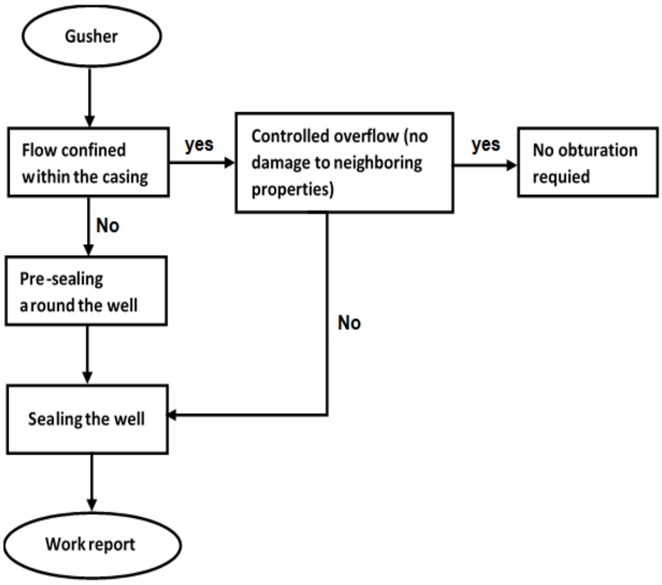

Figure 3. *Decision-making process leading to the plugging of a spouting well*

2.1.1 Preparation

Since the spout control device installed at the head of the artesian gushing well at Monzoungoudo is damaged (Fig. 5), before removing it, it is necessary to ensure that you have the necessary equipment to contain the flow from the well and the potential upwelling of the well sealing material.

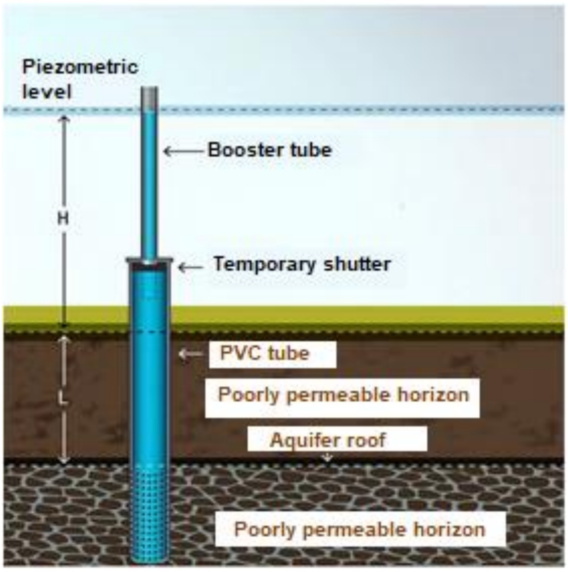

Figure 4. *Layout of a gushing well for measuring the piezometric surface*

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Figure 5. *Damaged wellhead equipment* [**2**]

2.1.2 Piezometric level and pressure at ground level

First, the piezometric level of the well must be determined (Fig. 4). The piezometric level represents the height above the ground surface at which the water level would be stabilized (in equilibrium with atmospheric pressure). To determine this level, it suffices to measure the height of the stabilized water level in relation to the ground surface (H).

To obtain the value of the piezometric level, the recommended methods consist of:

- Extending the casing until the water level stabilizes in the casing;
- Or equipping the well head with a pressure gauge. This second option measures the hydrostatic pressure at the end of the casing while the flow is blocked.

2.1.2.1 Calculation method by adding extra casing

Extension of the casing can be achieved by adding sections of steel pipe until the head of the casing exceeds the piezometric level. However, considering the springing nature of the well, it may prove to be simpler to equip the well with a pneumatic shutter with bypass pipe as shown in Figure 6, or with a mechanical shutter with by-pass (Fig. 7) and to provide them with an extra casing as an extension to the existing casing. The length of this extra casing must exceed the level of the piezometric surface (Fig. 4).

Note that the diameter of the extra casing has no impact on the measurement of the piezometric level since the hydrostatic pressure (p) which causes the water to rise in the casing is the product of the density of the liquid (ρ_{liquid}), the gravitational force (g) and the height of the water column above the measuring point (h) [4].

$$p = \rho_{liquid} \times g \times h \qquad \textbf{\textit{(1)}}$$

where:
P is pressure [bars], *g* is Gravity acceleration g [m/s^2] or [N/kg], and *h* is water column [m].

Once the piezometric surface has stabilized in the back-up casing (stopping the flow), the height (H) between the piezometric surface and the ground level can be measured (Fig. 4). This column of water above ground level is commonly called an "artesian water head". The artesian water head can then be converted to equivalent pressure to obtain the water pressure that would be measured at ground level. The conversion can be done as follows [7]:

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1 m water = 1.42 psi (9.8 kPa), or **(2)**
1 pi water = 0.433 psi (2.99 kPa) **(3)**

Figures 8 and 9 respectively convert the height of a water column (in meters or feet) into a pressure value of the international system or the imperial system.

2.1.2.2 Measurement method using a manometer

The manometer measurement method consists of fitting a manometer to the well head and reading the pressure measurement directly there. There are several options for arranging a wellhead so that a pressure gauge can be installed. Figure 10 shows one type of device for plugging the well while measuring the pressure at the end of the casing.

The pressure read on the manometer (Pm) represents the pressure that would be read at the base of the water column between the piezometric level and the manometer (Fig. 11). To obtain the value of the pressure at ground level, it is important to:

- measure the height of the manometer (Hm) from the ground;
- convert this height (Hm) into pressure by Formulas 2 or 3;
- and add this value to the pressure measurement read on the manometer (Pm) to obtain the total pressure at ground level.

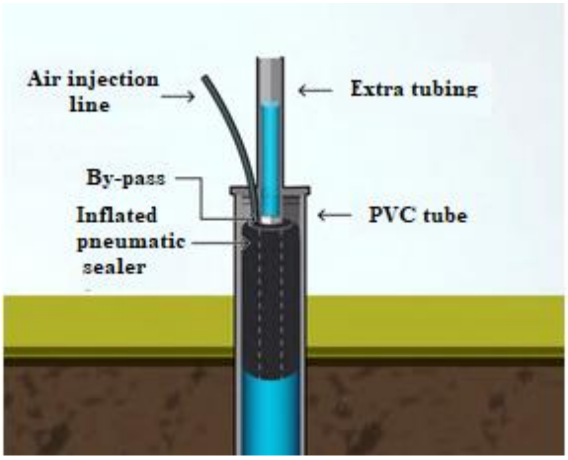

Figure 6. *Pneumatic shutter with bypass that can be fitted on a central casing for measuring the piezometric surface*

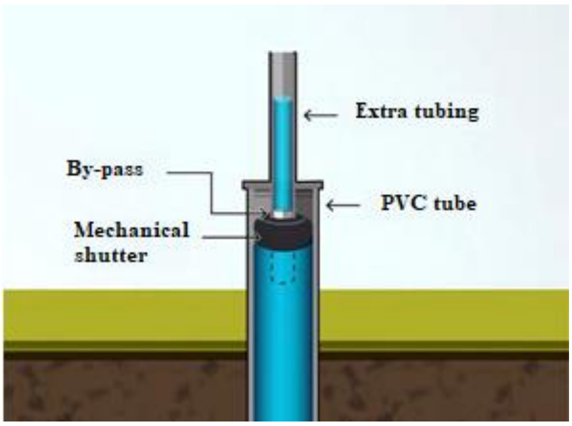

Figure 7. *Mechanical shutter with bypass that can be fitted on a central casing for measuring the piezometric surface*

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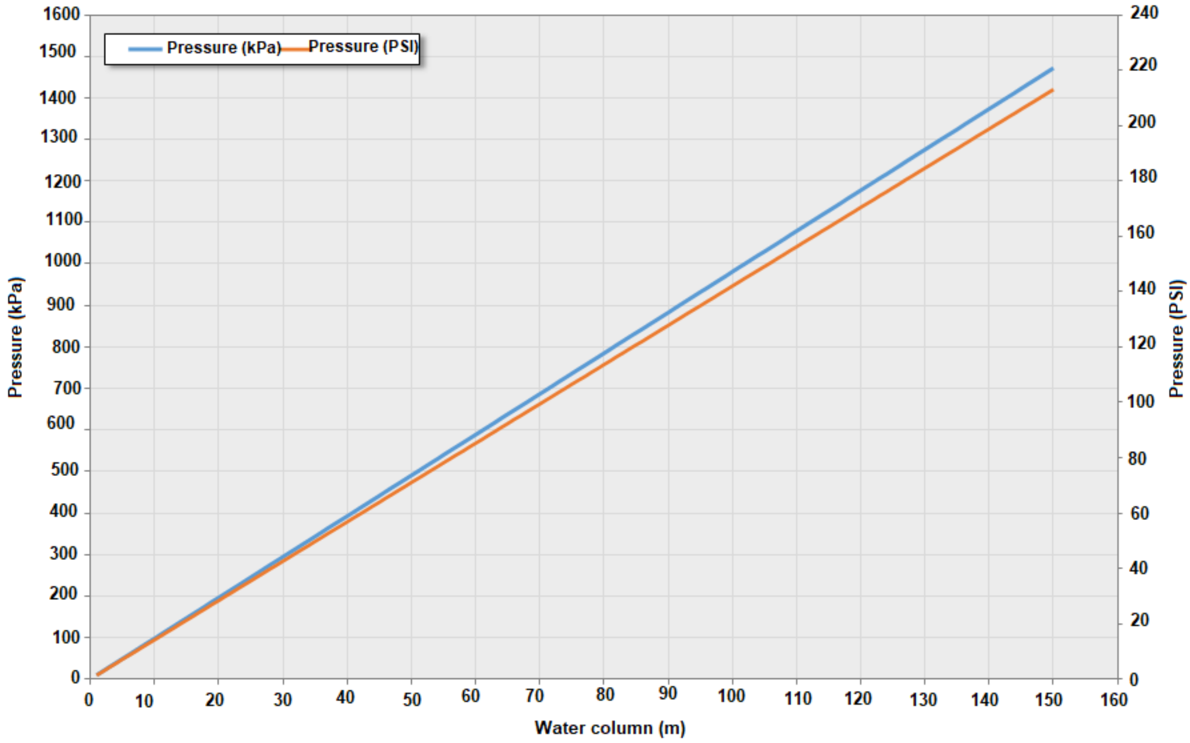

Figure 8. *Pressure equivalence chart as a function of thickness of the water column*

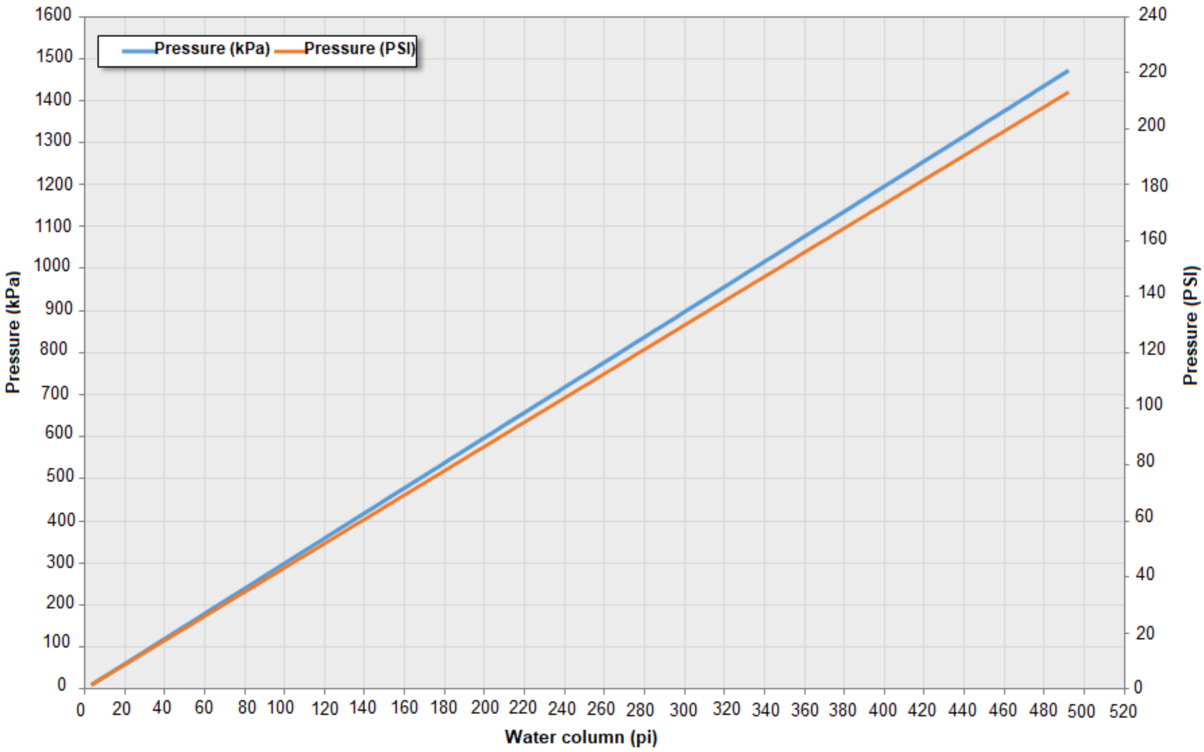

Figure 9. *Pressure equivalence chart as a function of thickness of the water column*

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If necessary, this value can be converted back to an artesian water head using Formulas 2 or 3 (see above), so as to obtain the height of the piezometric surface relative to the ground. This information will be required in the process of selecting the grout to be injected into the well.

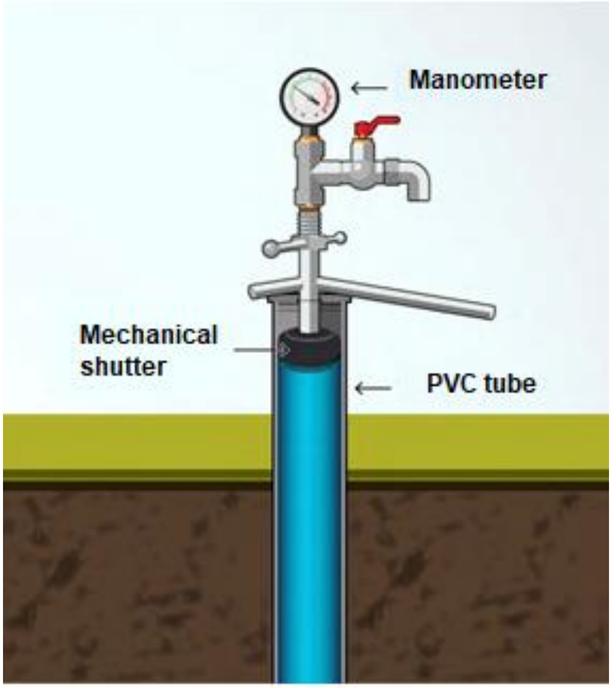

Figure 10. *Well head fitted with a shutter fitted with a pressure gauge*

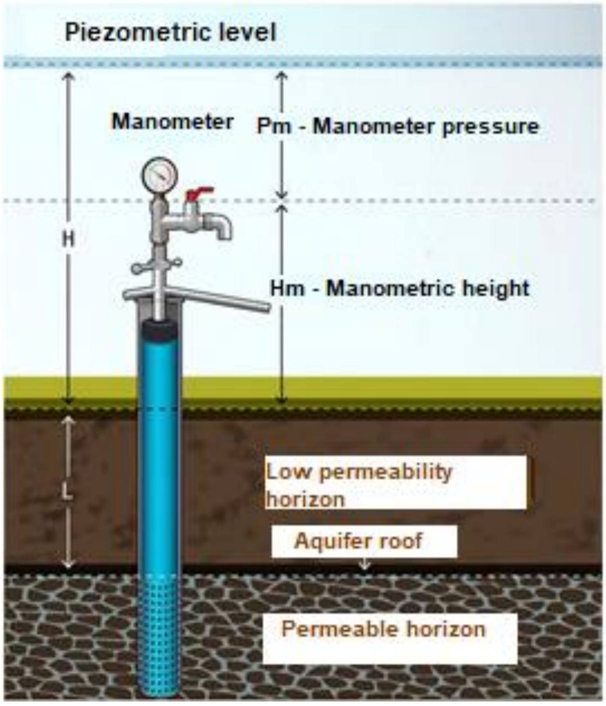

Figure 11. *Calculation of the piezometric level using a manometer*

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2.1.3 Hydrostatic pressure at the aquifer roof

To obtain the hydrostatic pressure at the roof of the aquifer, that is to say the hydrostatic pressure to be combated, the depth (L) corresponding to the difference between the roof of the aquifer and the surface of the ground must be added (Fig. 11), at the distance between the ground surface and the piezometric level (H). Subsequently, this sum (H + L) can be converted into pressure by Formulas 2 or 3. The depth (L) is measured during drilling and the information is usually available in the drilling report for any water withdrawal installation.

2.1.4 Selection of grout

To select the type of grout that will be poured into the well in order to combat the hydrostatic pressure and permanently seal the well, the hydrostatic pressure value obtained must be distributed over the depth (L). Thus, we obtain a pressure per unit of length with which it is possible to combine different types of grout. Table 1 gives a non-exhaustive list of products recommended in the literature.

Table 1. *Hydrostatic pressure of different types of grout* [**8**]

Grout	Density		Pressure per unit length	
	(kg/L)	*(lbs/gal)*	*(kPa/m)*	*(psi/pi)*
Thixotropic cement (4 gal water/sack*)	1.98	16.5	19.45	0.86
Pure cement (5.2 gal water / sack)	1.87	15.6	18.32	0.81
Pure cement (6.0 gal water / sack)	1.80	15.0	17.64	0.78
Bentonite grout (30% solids)	1.25	10.4	12.22	0.54
Bentonite grout (20% solids)	1.14	9.5	11.08	0.49
Granular bentonite/polymer slurry (15% solids)	1.10	9.2	10.86	0.48
Bentonite drilling fluid (viscosity 38 sec)	1.08	9.0	10.63	0.47
Water	1.00	8.3	9.73	0.43
* with cement friction reducer/fluid loss additive				

2.2 The data necessary for the plugging of the artesian well of Monzoungoudo

2.2.1 Geometry and hydrodynamics of the artesian well of Monzoungoudo

The data concerning the geometry and hydrodynamics of the borehole are grouped together in Table 2 and mainly concern the technical data of the hydraulic borehole carried out in the village of Monzoungoudo and which are provided by the General Directorate of Water of Benin (DGEau).

2.2.2 Lithological section of the artesian well of Monzoungoudo

The artesian well gushing from Monzoungoudo crosses all the geological formations in the study area. It is a rotary drilling, which produced cuttings [9]. The interpretation of the cuttings made it possible to recognize the geology of Mouzoungoudo and to carry out the log and the litho-stratigraphic section. The lithological section reveals a surface sedimentary level between 0 and 1m thick, formed of topsoil. Then, between 1 and 3 m there is a formation of lateritic clay. Between 3 and 15 m yellow clay spreads out. Between 15 and 57 m there is plastic clay. Between 57 and 75 m we find shell limestone.

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Table 2. *Geometric characteristics and hydrodynamic parameters of the artesian spouting well of Monzoungoudo* [1]

Geometric characteristics and hydrodynamic parameters from the artesian well of Monzoungoudo	
Settings	**Values**
Well depth H (m)	244.18
Well diameter D (m)	0.126
Flow Q (cm^3/s)	2000
Gravity acceleration g (m/s^2 or N/kg)	9.81
Wellhead pressure p_2 (bars)	4.16
Absolute pipe roughness ε (mm)	0.12

Between 75 and 135 m we find clayey limestone. Between 135 and 184 m we find more or less calcareous pyritic clay. Between 184 and 201 m we find an alternation of clay and limestone. Between 201 and 214 m we find sandy clay. Between 214 and 244.18 m we find fine and medium-grained white quartz sand. Figure 12 shows the cross section of the Monzoungoudo well.

3 RESULTS AND DISCUSSION

In this part, we will present the results obtained for the choice of grout as well as for its placement in the well.

3.1 Results: Choice of grout

The artesian well spouting Monzoungoudo at its piezometric surface (H) which is 3 meters from the ground surface intercepted the roof of the aquifer at a depth of 184 meters (L) from the ground. The height of the water at the top of the aquifer (H+L) is therefore 187 meters, which is equivalent to a calculated pressure of 1832.6 kPa (using Formula 1). Then, to know the pressure per unit of length to be used in the selection of the grout, the hydrostatic pressure calculated at the top of the aquifer (1832.6 kPa) must be divided by the length of the water column separating it from the ground surface (L=184 m). Thus, a value of 9.96 kPa/m is obtained. The next step is to select a grout whose density will counter an equivalent or greater hydrostatic pressure, as shown in Table 1. Here, a "bentonite drilling fluid (viscosity 38 sec)" grout would be acceptable.

3.2 Discussion: Placing the grout in the well

3.2.1 Filling of the section of the well open to the aquifer

The portion of the casing open to the aquifer must be filled with clean sand. However, before starting any filling, it is imperative to confirm the depth of the well by an in-situ measurement. This measurement will confirm the position of the bottom of the well and especially the absence of objects or residues obstructing the well. In the event that the depth measured on the site is lower than the data collected before the work (total depth available in the drilling report), it is recommended to inspect the well using a camera, so as to determine the source of the obstruction, and to rule on the possibility that this obstruction does not interfere with the work of plugging the well, in particular with the placement of the grout. It is only after the filling of the open section to the aquifer is complete that the sealing of the well can begin. Regardless of the type of aquifer used, filling must be carried out using an inert material (silica sand, clean gravel, etc.) so as to fill, at a minimum, the entire section of the open well to the top of the aquifer and minimize the loss of grout in the aquifer (Figs. 13A and 13B).

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3.2.2 Placement of the grout itself

The actual placement of the grout in the well will be done from the bottom up through an injection pipe (hopper), the end of which will be positioned slightly above the filling material, like illustrated in Figure 13B. When the pressure in the injection line is such that the efficiency of the placement of the grout will be affected or the consistency of the grout overflowing on the surface no longer shows any sign of dilution, the line can be gradually raised. The injection should be held in place until the consistency of the overflowing grout on the surface is the same as the consistency of the injected grout (Fig. 13C). The diameter chosen for the injection line must be as large as possible to facilitate the placement of the grout and limit the injection pressure.

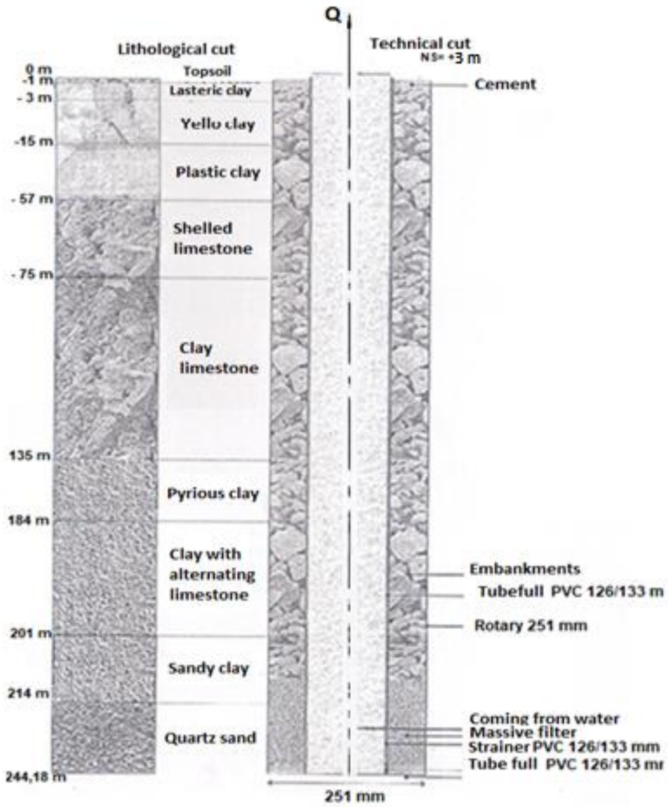

Figure 12. *Lithological section of the artesian well of Monzoungoudo* [1]

3.2.3 Removal of casing and components

Considering the probability that artesian pressures cause the creation of preferential paths along the outer surface of the casing, it is recommended to seal the area between the outer wall of the casing and the surrounding unconsolidated deposits. There are two ways to achieve this, depending on whether the casing can be removed or not. If the casing can be removed, this should be done during the injection of the grout or immediately after its placement, before the latter begins to set (Fig. 13D). Following the removal of the casing, the level of the grout in the well may decrease. In this case, it is required to make up for this decrease by adding an additional volume of grout so that the final level is one meter from the ground surface. In a context where the casing cannot be removed, it is recommended to perforate the casing so as to allow the injection of grout in contact with the casing and unconsolidated deposits, over the entire contact. ASTM D-5299 [10] recommends drilling the casing to allow the grout to enter along the contact between the surrounding unconsolidated deposits and the outer surface of the casing (Fig. 13E). This standard proposes the arrangement of a minimum of four perforations of a few centimetres in length distributed over the same level of the periphery of the casing. This perforation pattern should be repeated vertically with five rows of perforations per ± 0.3meter (1 foot) section of casing. An alternative to this approach would be to cut the casing directly above the screen (for wells in overburden) and remove the casing afterwards.

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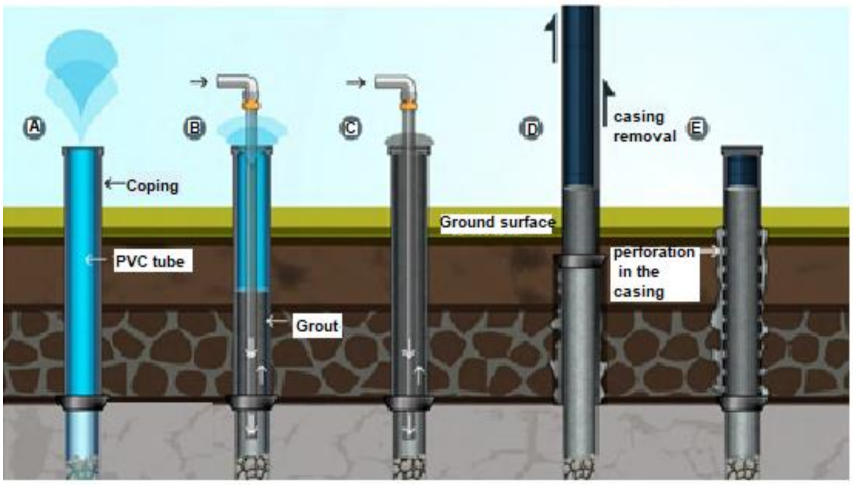

Figure 13. *Sequence of sealing of a spouting artesian well (A, B,C,D,E)*

4 CONCLUSION

The objective of this study is to plug the artesian well spouting Monzoungoudo in order to restore the hydrogeological conditions of the original aquifer, that is to say the conditions inherent in the aquifer prior to the well drilling work, so as to avoid the potential nuisance of the spout. To achieve this objective a "bentonite drilling fluid (viscosity 38 sec)" grout was selected for the sealing of the well from the archival data (geological, hydrogeological, piezometric, etc.) of the well. Thus, this structure can be controlled and will no longer cause damage to the environment.

In general, the abandonment and sealing of wells is therefore an aspect in its own right in the protection of the environment and in particular in the protection of groundwater resources, since an abandoned well is a fragile point in the system which, if not properly treated, can be the cause of pollution or more or less serious changes in groundwater resources.

It is therefore a serious problem that must be treated carefully, taking into account the technical requirements and recommendations listed in this paper as the rules of the art. The techniques involved in these actions require a detailed analysis of the hydrogeological context and the conditions of realization of a work to respond to each particular case.

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